Contemporary analysis of the intraoperative and perioperative complications of neurosurgical procedures performed in the sitting position

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OBJECTIVE Historically, performing neurosurgery with the patient in the sitting position offered advantages such as improved visualization and gravity-assisted retraction. However, this position fell out of favor at many centers due to the perceived risk of venous air embolism (VAE) and other position-related complications. Some neurosurgical centers continue to perform sitting-position cases in select patients, often using modern monitoring techniques that may improve procedural safety. Therefore, this paper reports the risks associated with neurosurgical procedures performed in the sitting position in a modern series.

METHODS The authors reviewed the anesthesia records for instances of clinically significant VAE and other complications for all neurosurgical procedures performed in the sitting position between January 1, 2000, and October 8, 2013. In addition, a prospectively maintained morbidity and mortality log of these procedures was reviewed for instances of subdural or intracerebral hemorrhage, tension pneumocephalus, and quadriplegia. Both overall and specific complication rates were calculated in relation to the specific type of procedure.

RESULTS In a series of 1792 procedures, the overall complication rate related to the sitting position was 1.45%, which included clinically significant VAE, tension pneumocephalus, and subdural hemorrhage. The rate of any detected VAE was 4.7%, but the rate of VAE requiring clinical intervention was 1.06%. The risk of clinically significant VAE was highest in patients undergoing suboccipital craniotomy/craniectomy with a rate of 2.7% and an odds ratio (OR) of 2.8 relative to deep brain stimulator cases (95% confidence interval [CI] 1.2–70, p = 0.04). Sitting cervical spine cases had a comparatively lower complication rate of 0.7% and an OR of 0.28 as compared with all cranial procedures (95% CI 0.12–0.67, p < 0.01). Sitting cervical cases were further subdivided into extradural and intradural procedures. The rate of complications in intradural cases was significantly higher (OR 7.3, 95% CI 1.4–39, p = 0.02) than for extradural cases. The risk of VAE in intradural spine procedures did not differ significantly from sitting suboccipital craniotomy/craniectomy cases (OR 0.69, 95% CI 0.09–5.4, p = 0.7). Two cases (0.1%) had to be aborted intraoperatively due to complications. There were no instances of intraoperative deaths, although there was a single death within 30 days of surgery.

CONCLUSIONS In this large, modern series of cases performed in the sitting position, the complication rate was low. Suboccipital craniotomy/craniectomy was associated with the highest risk of complications. When appropriately used with modern anesthesia techniques, the sitting position provides a safe means of surgical access.

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KEY WORDS sitting position; venous air embolism; posterior fossa surgery; surgical technique

Use of the sitting position in neurosurgery has long been a matter of some debate.32 Interest in its use stems from a number of perceived advantages relative to other positions, particularly for procedures involving the posterior fossa and cervical spine. These advantages include improved venous drainage due to reduced thoracic outlet pressure, improved visualization of the surgical field, and reduced need for cerebellar retraction in posterior fossa cases.15,32 In some instances, specifically deep brain stimulator (DBS) implantation, the use of the sitting position is preferred to ensure appropriate access and patient comfort as well as to minimize brain shift during the procedure.
These benefits must be weighed against perceived complications inherent to the sitting position. Venous air embolism (VAE), postoperative quadriplegia, tension pneumocephalus, and subdural hematomas have been reported.\textsuperscript{15,28,37} In much of the reported literature, these complications occur at very low rates, but the results can be devastating when they do occur. However, modern techniques to prevent, monitor, diagnose, and rapidly treat these complications can potentially improve outcome.\textsuperscript{14} This is supported by a number of recent series that have demonstrated reduced rates of complications, particularly VAE, relative to older studies.\textsuperscript{15,21,37} These results suggest that rather than abandoning this procedure as has occurred at many centers, modern techniques aimed at recognizing VAE may mitigate complications associated with the sitting position, improving its safety. In this paper we report a modern series of 1792 procedures performed in the sitting position from January 1, 2000, to October 8, 2013.

Methods

Study Population

Institutional Review Board approval was obtained prior to data collection. Patients undergoing DBS electrode placement, suboccipital craniotomy/craniectomy, and procedures involving the posterior cervical spine in the sitting position between January 1, 2000, and October 8, 2013, were included. Patients undergoing percutaneous procedures or refusing consent for research were excluded. Morbidity and mortality logs, operative reports, and electronic medical records were reviewed for instances of detected VAE, clinically significant VAE (defined as those cases requiring anesthetic intervention), subdural hematoma, tension pneumocephalus, and postoperative quadriplegia. The morbidity and mortality log represents a prospectively maintained database of immediate and near-term postoperative complications (within 30 days of the procedure) as recorded by providers in the Department of Neurological Surgery. Preoperatively, there were no predetermined criteria as to what cases were to be performed in the sitting position. Surgeon preference was the deciding factor, with consultation with the anesthesiologist at the time of surgery.

Postoperative hemorrhages, including subdural hematomas, were part of the analysis if listed as an immediate or short-term complication in the morbidity and mortality log during the acute hospital period. Cases of tension pneumocephalus were included if intervention was required in the form of twist-drill evacuation. The overall incidence of complications as well as individual complication rates was analyzed. Further subset analysis was performed according to procedure type.

Data Collection

Cases of VAE were identified based on specific documentation in the anesthesia record. This was performed via a database query of the included cases for the terms “VAE,” “venous air embolism,” “air embolism,” “air emb-,” “air he-,” “air se-,” “air id-,” and “air bu-.” The results of the query were manually reviewed to ensure the accuracy of the included cases. The diagnosis of VAE was made intraoperatively. This diagnosis was made at the discretion of the documenting physician based on clinical findings and intraoperative fluctuations in the patient’s vital signs. Cases of VAE were not diagnosed retrospectively. Cases of VAE were retrospectively classified as mild (requiring no intervention), moderate (a significant drop in end-tidal CO\textsubscript{2}, or hemodynamic instability requiring support with vasopressors), or severe (moderate criteria with the addition of emergency repositioning or use of Advanced Cardiopulmonary Life Support [ACLS] resuscitation). A case of VAE was deemed clinically significant if it was classified in the moderate or severe categories.

Intraoperative Monitoring

Intraoperative monitoring to aid in the diagnosis of VAE was case-dependent. Sitting cranial cases typically included precordial Doppler ultrasonography, transesophageal echocardiography (TEE), and placement of a central line for central venous pressure monitoring. Anesthesia was maintained with isoflurane, with or without nitrous oxide or desflurane and short-acting narcotics. Cervical spine cases used similar monitoring and anesthesia to cranial cases but without central venous pressure monitoring. DBS cases were monitored with precordial Doppler ultrasonography only. DBS cases typically proceeded under monitored sedation with dexmedetomidine; in cases in which general anesthesia was required, maintenance proceeded with isoflurane or sevoflurane with or without nitrous oxide. The typical intraoperative positioning of a patient, as well as the intraoperative monitoring configuration, is presented in Fig. 1. A retrospective review of the intraoperative anesthesia record was undertaken to assess the incidence of VAE based on precordial Doppler monitoring, changes in end-expired CO\textsubscript{2}, and changes in hemodynamic stability. Preoperative risk assessment, such as with bubble echocardiography, was not routinely undertaken.

Statistical Analysis

Statistical analysis was performed using Microsoft Excel and MedCalc online to calculate the odds ratio (OR), 95% confidence interval (CI), and statistical significance of complications during a given type of procedure. Cases were broadly divided into sitting suboccipital craniotomy/craniectomy, DBS, or cervical spine procedures. Complications in sitting suboccipital cases were compared with those in DBS procedures. Cervical spine procedures were further categorized as either intradural or extradural, and the risk of VAE was compared between these two groups.

Results

Demographics

A total of 1792 procedures were identified during the time interval of the study. The overall series consisted of 41% female patients with a median age of 54 years (range 3–92 years). Further demographic data can be found in Table 1.

Events

The overall complication rate related to the procedure was 1.45% (26/1792 procedures). The incidence rates of
clinically significant (moderate or severe) VAE, tension pneumocephalus, and subdural or remote hemorrhage were 1.06%, 0.11%, and 0.28%, respectively, inclusive of all procedures. There were no intraoperative deaths; however, 1 patient died within 30 days of the procedure.

Procedure-Specific Data

Among sitting suboccipital procedures (450 cases), the rates of clinically significant VAE, tension pneumocephalus, and hemorrhage (1 subdural and 1 remote) were 2.7%, 0.2%, and 0.4%, respectively, with an overall complication rate of 3.3% (Table 2). In 332 DBS cases, there was a 0.3% incidence of clinically significant VAE and a 0.9% incidence of subdural hemorrhage, with no cases of tension pneumocephalus. Within the 1010 included cervical spine cases, there was a 0.7% incidence of clinically significant VAE and a 0.9% incidence of subdural hemorrhage, with no cases of tension pneumocephalus. Within the 1010 included cervical spine cases, there was a 0.7% incidence of clinically significant VAE and a 0.9% incidence of subdural hemorrhage, with no cases of tension pneumocephalus. When separated into intradural and extradural cervical spine cases, the rates of clinically significant VAE were 1.8% and 0.5%, respectively (Table 3). The lone case of tension pneumocephalus noted in a sitting cervical procedure occurred in an intradural case. No neurological deficits were directly attributable to patient positioning in any of the included cases. Sitting cervical procedures were overall associated with fewer complications than cranial procedures (OR 0.28, 95% CI 0.12–0.67, p = 0.0042).

The occurrence of clinically significant VAE (OR 9.07, 95% CI 1.17–70.09, p = 0.035) was more strongly associated with suboccipital procedures as compared with DBS implantation, but overall complication rates were comparable (OR 2.83, 95% CI 0.93–8.6, p = 0.67; Table 2). There was no significant difference in the risk of hemorrhage or tension pneumocephalus between the two groups (p = 0.435 and p = 0.626, respectively), although there were no incidences of tension pneumocephalus occurring in DBS cases in this series.

In cervical spine cases, intradural procedures (n = 54) were more strongly associated with mild (clinically insignificant) VAE compared with extradural cervical spine cases (n = 956; OR 6.87, 95% CI 2.38–19.38, p = 0.0004; Table 4). However, when limited to clinically significant VAE (moderate or severe), there was no significant difference (OR 3.59, 95% CI 0.41–31.27, p = 0.247; Table 3). Intradural cases were also associated with a significantly higher risk of tension pneumocephalus relative to extradural procedures (OR 53.64, 95% CI 2.16–1332.35, p = 0.015; Table 3). When compared with sitting suboccipital cranial procedures, there was not a statistically significant difference in the risk of clinically significant VAE in intradural cervical procedures (p = 0.723; Table 3). There was no incidence of clinically significant postoperative hemorrhage in either group.

No deaths resulted from any of the observed complications; the single death within 30 days of the procedure was unrelated to the procedure performed. Two procedures (2/1792) were aborted due to intraoperative VAE.

Cases of VAE were subdivided into mild, moderate, and severe categories, based on changes in end-expired CO_2 or hemodynamic instability requiring intervention. Mild cases required no intervention; moderate cases involved a significant decrease in end-expired CO_2 requiring use of vasopressor support; and severe cases required emergency repositioning or ACLS resuscitation. Mild cases of VAE were significantly associated with suboccipital craniotomy/craniectomy relative to DBS procedures (p = 0.001, Table 4). Similarly, mild cases of VAE were also significantly more frequent in intradural cervical spine cases (5 of 54) as compared with extradural procedures (14 of 956; p = 0.0004, Table 4). There was not a significant association between moderate or severe VAE in comparing either

FIG. 1. Illustrative setup for sitting procedure. The patient is placed in a Mayfield pinion, the table is maximally flexed (A and B), and the patient secured to a Mayfield cross bar adapter (C). An antebrachial peripherally inserted central catheter is also placed prior to positioning (D). Figure is available in color online only.

TABLE 1. Demographic data

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. of Cases</th>
<th>Women (%)</th>
<th>Median Age (range)</th>
<th>Males Age (range)</th>
<th>Females Age (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>1792</td>
<td>736 (41)</td>
<td>54 (3–92)</td>
<td>56 (3–92)</td>
<td>51 (7–92)</td>
</tr>
<tr>
<td>Cervical</td>
<td>1010</td>
<td>354 (35)</td>
<td>54 (17–92)</td>
<td>55 (17–92)</td>
<td>51 (23–92)</td>
</tr>
<tr>
<td>DBS</td>
<td>332</td>
<td>125 (38)</td>
<td>62 (9–84)</td>
<td>62 (9–84)</td>
<td>64 (9–83)</td>
</tr>
<tr>
<td>Suboccipital</td>
<td>450</td>
<td>257 (57)</td>
<td>45 (3–83)</td>
<td>47 (3–81)</td>
<td>43 (7–83)</td>
</tr>
</tbody>
</table>
extradural with intradural cervical cases or suboccipital craniotomy/craniectomy with DBS cranial cases (Table 4).

**Discussion**

Despite the potential advantages of the sitting position, hesitancy regarding its implementation persists among some neurosurgeons and anesthesiologists, precluding its widespread use. This negative stigma is partially due to increased risk of VAE, but also due to other rare and severe complications that have been attributed to sitting procedures. Our institution has an extensive history of performing neurosurgical procedures in the sitting position.\(^3,^7,^11\) To better ascertain the true nature of these risks, we reviewed a large modern series \((n = 1792, \text{from January 1, 2000, until October 8, 2013})\) of various neurosurgical procedures performed in the sitting position. The overall incidence of complications attributable to the sitting position was 1.45%. The overall incidence of VAE requiring intraoperative treatment was 1.1%. The incidence of VAE increased to 4.7% when all cases of VAE were included; however, these additional occurrences responded to minimal field interventions such as waxing bone edges, cauterizing vessels, or copious irrigation. No deaths resulted from any of the observed complications, and only 2 procedures \((2/1794)\) were aborted due to intraoperative VAE.

**Venous Air Embolism**

The reported incidence of VAE during sitting neurosurgical procedures is extremely variable in the literature and largely depends on the way that VAE was defined, as well as the patient population. The methods used to detect VAE have also evolved over time.\(^6,^23\) In our series, we emphasized clinically significant VAE, meaning a VAE resulting in hemodynamic or respiratory compromise, or alteration of the course of the case. Recently, Ganslandt and colleagues \((2013)\) reviewed more than 600 suboccipital and cervical spine procedures and evaluated the incidence of VAE as defined by a decrease in end-expired CO\(_2\) of more than 4 mm Hg, characteristic sounds on Doppler ultrasonography, or any sign of air on TEE. The overall incidence in their series was 19%. However, the incidence of VAE causing hemodynamic or respiratory compromise was 3.3%, and only 1 in 200 cases had to be terminated due to VAE.\(^15\) Using a similar definition, Leslie et al. \((2006)\) found an overall incidence of 9%, also in a mixture of cervical and suboccipital cases.\(^24\) In contrast, Papadopoulos et al. \((1994)\) prospectively reviewed 22 posterior fossa cases and 40 cervical spine cases, defining VAE solely by using TEE, and reported an incidence of 76% and 25%, respectively.\(^31\) However, the incidence of VAE detected in this manner is not known for other surgical positions.

Perhaps the most comprehensive study using variable definitions of VAE is that conducted by Feigl et al., who reviewed 200 consecutive semisitting neurosurgical cases in 2014. Using a graded scale, they found the incidence to be 42.3% if a definition of the presence of air bubbles on TEE was used, compared with 3.8% if a decrease in end-expired CO\(_2\) of more than 3 mm Hg was used and 1.9% if clinically significant changes (drop in mean arterial pressure > 20% or increase in heart rate > 40%) were used. No VAEs resulted in hemodynamic instability requiring resuscitation.\(^13\) While series that use the most stringent of definitions for VAE reveal that air passes into systemic circulation with no small frequency, it is worthy of note that comparably few VAEs involve adverse consequences. A review of 430 posterior fossa cases by Bithal et al. showed that 37% of VAEs (defined as a sustained decrease in end-tidal CO\(_2\) by > 0.7 kPa) in adults and 33% in children resulted in hypotension, and only in one instance was it necessary to abort a procedure.\(^2\) Furthermore, VAE is a risk of any procedure in which the head is above the heart, and there is scant literature to determine what the exact incidence of VAE is in these cases. As reverse Tren-

**TABLE 2. Overall and specific complication rates for sitting suboccipital craniotomies and DBS cases**

| Cranial Cases | Complications (%) | OR | 95% CI | p  
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Overall</td>
<td>24 (3.1)</td>
<td>2.83</td>
<td>0.93–8.6</td>
<td>0.067</td>
</tr>
<tr>
<td>Suboccipital</td>
<td>15 (3.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBS</td>
<td>4 (1.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate/severe VAE</td>
<td>9.07</td>
<td>1.17–70.09</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Suboccipital</td>
<td>12 (2.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBS</td>
<td>1 (0.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension pneumocephalus</td>
<td>2.22</td>
<td>0.09–54.65</td>
<td>0.626</td>
<td></td>
</tr>
<tr>
<td>Suboccipital</td>
<td>1 (0.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBS</td>
<td>0 (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>0.48</td>
<td>0.08–2.95</td>
<td>0.435</td>
<td></td>
</tr>
<tr>
<td>Suboccipital</td>
<td>2 (0.4)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DBS</td>
<td>3 (0.9)</td>
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* Odds ratios are presented comparing suboccipital craniotomy/craniectomy to DBS for each complication and overall, along with a 95% CI and associated p values.

**TABLE 3. Risk of complications in intradural cervical procedures compared with extradural cervical procedures and sitting suboccipital craniotomy/craniectomy cases**

| Cervical Spine Cases | Complications (%) | OR | 95% CI | p  
<table>
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<tr>
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<tbody>
<tr>
<td>Overall</td>
<td>7 (0.7)</td>
<td>7.32</td>
<td>1.39–38.61</td>
<td>0.019</td>
</tr>
<tr>
<td>Intradural</td>
<td>2 (3.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extradal</td>
<td>5 (0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate/severe VAE</td>
<td>3.59</td>
<td>0.41–31.27</td>
<td>0.247</td>
<td></td>
</tr>
<tr>
<td>Intradural</td>
<td>1 (1.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extradal</td>
<td>5 (0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension pneumocephalus</td>
<td>53.64</td>
<td>2.16–1332.35</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>Intradural</td>
<td>1 (1.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extradal</td>
<td>0 (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk of moderate/severe VAE</td>
<td>0.69</td>
<td>0.09–5.40</td>
<td>0.723</td>
<td></td>
</tr>
</tbody>
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delenburg positioning is very commonly employed to reduce brain swelling. VAE has been reported in horizontal neurosurgical cases, although the incidence is higher with sitting procedures.\textsuperscript{12}

Interestingly, the incidence of VAE appears to differ with the type of procedure as well. We found that cranial cases, both suboccipital craniotomies (2.7\%) and intradural cervical spine cases (1.8\%), had higher incidences of clinically significant VAE compared with DBS cases (0.3\%) and extradural cervical cases (0.5\%). While the reasons for these findings are not entirely clear, they have also been borne out in other series.\textsuperscript{12,15} In a meta-analysis of more than 4000 cases, Fathi et al. found a nearly 3-fold increase in the incidence of VAE during posterior fossa procedures compared with cervical cases.\textsuperscript{12} The incidence in 467 DBS cases was 1.3\% as reported by Chang et al.\textsuperscript{4} Additionally, the type of suboccipital craniotomy may also play a role, as Yonekawa and colleagues reported higher rates with lateral approaches (21\% vs 8\%).\textsuperscript{43} The incidence rate may also vary with operative time, as 1 study that reviewed the utility of image guidance with lateral suboccipital craniotomy found lower incidences of VAE (8\% vs 19\%) and faster operative times (21 vs 39 minutes) in cases that used image guidance compared with cases in which this technology was not used.\textsuperscript{16} However, it should be noted that cases using image guidance had lower rates of venous sinus injury that may also account for this difference. The difference in risks may in part be explained by lower degrees of invasiveness given that craniotomies/craniectomies have greater risk than DBS procedures. Cerebrospinal fluid egress also likely plays a role as the cervical cases in this series were mostly decompressive laminectomies and foraminotomies, with a smaller representation of intradural procedures in which a higher, but not statistically significant, rate of clinically significant VAE was observed.

### Pneumocephalus

Pneumocephalus is a common occurrence with any cranial procedure, and is a gravity-dependent phenomenon. Thus, it is not surprising that the reported incidence of pneumocephalus after sitting procedures is higher than procedures performed in the horizontal position.\textsuperscript{48} However, tension pneumocephalus, a potential expanding volume of air that results in an increase in intracranial pressure, is rare and is not necessarily unique to sitting neurosurgical cases.\textsuperscript{20,33,39} Di Lorenzo conducted a prospective study of 30 cases and found a 100\% occurrence of pneumocephalus, although no patient suffered tension pneumocephalus or any neurologological symptom as the result of intracranial air.\textsuperscript{10} A larger study conducted by Standefar et al. of 488 cases found that only 8 patients (1.6\%) developed symptomatic pneumocephalus, none of whom required twist-drill bur hole and aspiration through a subdural catheter to relieve pressure.\textsuperscript{37}

### Subdural and Remote Hemorrhages

The development of subdural hemorrhage was exceedingly rare in the present series. No subdural hematomas occurred after cervical cases, and 5 patients developed a subdural hematoma after a cranial case (3 DBS cases and 2 posterior fossa cases). Standefar et al. also reported a low subdural hematoma rate (0.6\% after all cases and 1.3\% after posterior fossa cases) following sitting procedures.\textsuperscript{37} Presumably, the cause for subdural hematomas is related to mechanical displacement of the brain resulting in tearing of bridging veins. While this appears to be a logical explanation, it does not fully explain the findings of remote intraparenchymal or epidural hemorrhages that have been observed after sitting procedures.\textsuperscript{4,22,30} Furthermore, it is debatable as to whether the sitting position truly leads to an increase in these complications, as these complications are observed in more conventional positions as well. Although Brisman et al. found that 87\% of remote hemorrhages occurred in the sitting procedures in his review of the literature, a large series by Kalfas and Little that reviewed nearly 5000 supratentorial and infratentorial cases did not find an increased risk with the sitting position.\textsuperscript{4,22}

### Other Neurological and Rare Complications

Although no neurological complications were directly attributable to the sitting position in our series, a variety of neurological complications have been described as a result of its use.\textsuperscript{19,23,27,29,38,41} Sciatic nerve palsies have been described with the use of the sitting position.\textsuperscript{23,41} Other cranial nerve palsies have also been described such as delayed lateral rectus palsies and anosmia.\textsuperscript{34,38} These reported complications range from minor complications such as peripheral and cranial nerve palsies to devastating complications such as cervical quadriplegia. Peripheral nerve palsies that have been described due to the sitting position include sciatic nerve injury.\textsuperscript{34,35,38} One of the most feared complications is cervical quadriplegia due to cord stretch.\textsuperscript{42} Both cord infarction and quadriplegia have been described.\textsuperscript{19,27,29} While such complications are likely exceedingly rare, they do emphasize the necessity for meticulous positioning and support the use of monitoring (motor and somatosensory evoked potentials) for pre-

<table>
<thead>
<tr>
<th>Severity of VAE</th>
<th>Suboccipital</th>
<th>DBS</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
<th>Intradural</th>
<th>Extradural</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>38</td>
<td>8</td>
<td>3.74</td>
<td>1.72–8.12</td>
<td>0.001</td>
<td>5</td>
<td>14</td>
<td>6.87</td>
<td>2.38–19.83</td>
<td>0.0004</td>
</tr>
<tr>
<td>Moderate</td>
<td>9</td>
<td>1</td>
<td>6.75</td>
<td>0.85–53.58</td>
<td>0.071</td>
<td>1</td>
<td>5</td>
<td>3.59</td>
<td>0.41–31.27</td>
<td>0.247</td>
</tr>
<tr>
<td>Severe</td>
<td>3</td>
<td>0</td>
<td>5.2</td>
<td>0.28–101.04</td>
<td>0.276</td>
<td>0</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* Cases were stratified as mild, moderate, or severe based on the following criteria: mild = diagnosis of VAE without clinical significance or need for pharmacological, anesthetic, or surgical intervention; moderate = diagnosis of VAE with significant drop in end-tidal CO2 or requiring pressor support; severe = moderate criteria in addition to emergency repositioning or requiring ACLS resuscitation.
vvention. Other rare complications that have been reported after sitting procedures include acute parotitis, pyriformis syndrome, and tension pneumoventricle.\(^1\)\(^,\)\(^5\)\(^,\)\(^18\) We did not observe these complications in this series, and our series likely represents a more modern approach to these cases compared with the prior report. Additionally, consequences of VAE such as paradoxical emboli in the presence of patent foramen ovale (PFO) or due to right-to-left intrapulmonary shunting and fatal coagulopathy have been described.\(^12\)\(^,\)\(^17\)\(^,\)\(^26\)\(^,\)\(^36\) Due to the risk of paradoxical emboli, the presence of PFO is considered a contraindication to the sitting position by some, and efforts have been undertaken to identify patients undergoing sitting procedures where there may be a PFO.\(^9\) However, in a series of 200 patients undergoing semisitting procedures, 52 of whom had a PFO, no instances of paradoxical emboli were reported by Feigl et al. using modern protocols for VAE detection.\(^13\)

**Limitations of the Study**

The present series has value in its large sample size and derivation from a prospectively collected morbidity and mortality database. However, because the database is maintained by neurosurgical staff, attention to anesthetic complications (such as delayed extubation or macroglia) would likely not be captured in this cohort. Thus, the overall complication rate may well be higher if all anesthetic-related complications are considered. Additionally, our definition of VAE makes it difficult to compare incidences among other institutions or other series that may use more stringent definitions. We did endeavor to separately review the intraoperative anesthetic data to assess the incidence of VAE from a different perspective to address these issues. The lack of any set criteria in the selection of patients to undergo surgery in the sitting position may also present a confounding variable. Similarly, the variability of methods used to detect VAE (such as the use of TEE in suboccipital cases but not in DBS) may lead to some ascertainment bias in the detection of mild VAE. However, this variation is unlikely to obscure the detection of moderate or severe cases of VAE as these cases involved some evidence of hemodynamic instability requiring intervention. Lastly, the heterogeneity of procedures (cervical, suboccipital, and DBS cases) may also preclude direct comparisons to other prior series that did not include these specific types of procedures. We used data from a neurosurgical morbidity and mortality database, and events that may have occurred at a later time (past the first 30 days postoperatively) were unlikely to be captured. Future study assessing the risk factors for complications among different procedure types would be of value to better understand which subset of patients is truly at risk to further mitigate the risk of these complications.

**Conclusions**

In this large, modern series of cases performed in the sitting position, the overall rate of complications was quite low. No neurological deficits were observed directly as a result of positioning (i.e., quadriplegia). While the risk of VAE has been shown to be higher in sitting procedures, the overall risk of clinically significant VAE in this study was small at 1.1%. The risk of clinically significant VAE is higher in suboccipital cases relative to DBS procedures. While a higher rate of clinically significant VAE was observed in intradural cervical cases relative to extradural ones, it did not reach statistical significance. There was, however, a significantly higher rate of mild VAE in intradural cases. When appropriately used, the sitting position provides a safe means of surgical access.

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**References**


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Van Gompel, Himes, Mallory, Abcejo. Acquisition of data: Himes, Mallory, Abcejo, Pasternak, Atkinson, Meyer, Marsh, Link, Clarke. Analysis and interpretation of data: Himes, Mallory, Abcejo. Drafting the article: Van Gompel, Himes, Mallory, Abcejo, Pasternak. Critically revising the article: Van Gompel, Himes, Mallory, Abcejo, Pasternak. Approved the final version of the manuscript on behalf of all authors: Van Gompel. Statistical analysis: Himes, Mallory.

Supplemental Information
Previous Presentations
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